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NEW GUN CAPABILITY WITH INTERCHANGABLE BARRELS TO INVESTIGATE LOW VELOCITY IMPACT REGIMES AT THE LAWRENCE LIVERMORE NATIONAL LABORATORY HIGH EXPLOSIVES APPLICATIONS FACILITY

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NEW GUN CAPABILITY WITH INTERCHANGABLE BARRELS TO INVESTIGATE LOW VELOCITY IMPACT REGIMES AT THE LAWRENCE LIVERMORE NATIONAL LABORATORY HIGH EXPLOSIVES APPLICATIONS FACILITY

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Summary— A new gas gun capability is being activated at Lawrence Livermore National Laboratories located in the High Explosives Applications Facility (HEAF). The single stage light gas (dry air, nitrogen, or helium) gun has interchangeable barrels ranging from 25.4 mm to 76.2 mm in diameter with 1.8 meters in length and is being fabricated by Physics Applications, Inc. Because it is being used for safety studies involving explosives, the gun is planned for operation inside a large enclosed firing tank, with typical velocities planned in the range of 10-300 m/s. Three applications planned for this gun include: low velocity impact of detonator or detonator/booster assemblies with various projectile shapes, the Steven Impact test that involves impact initiation of a cased explosive target, and the Taylor impact test using a cylindrical explosive sample impacted onto a rigid anvil for fracture studies of energetic materials. A highlight of the gun features, outline on work in progress for implementing this capability, and discussion of the planned areas of research will be included.

INTRODUCTION

Lawrence Livermore National Laboratory (LLNL) is continuing to expand on the capabilities for doing impact and shock wave work by implementing a new gun capability with interchangeable barrels to investigate low velocity impact regimes. We have named it the Dynamic Energetic Materials Impact and Ignition Gun or “DEMII Gun” for short. The key features of the gun include a velocity range of ~10-300 m/s that fills a gap in the current capability, interchangeable 25.4, 50.8, and 76.2 mm barrels, and a breech design that includes “regenerative valve” and “ball-valve” types. This is a portable system with short barrels to be used inside the existing explosive firing tank where a 100 mm gun already exists. The new gun has been designed and fabricated by Physics Applications, Inc. in Dayton, Ohio.

Similar to other national laboratories, academic institutions, and military laboratories that do shock wave research, LLNL has a rich history in gun facilities to launch projectiles for producing shock waves and performing impact studies [1-8]. The main facility at LLNL doing this research is the High Explosives Applications Facility (HEAF) [8] and will be the location for this new gun. The HEAF, originally brought on line in April of 1989 [3], already has a 100 mm single stage propellant driven gun and will soon add this new gun as well as other gun capabilities because it does not perform consistently in the lower velocity regime around 300 m/s.

All of the capabilities already available in the HEAF 100 mm gun area will also be available for experiments with this gun and include manganin pressure gauges, electromagnetic particle velocity gauging, 450 KeV flash x-ray (3 heads), Photonic Doppler Velocimetry (PDV), and 5 beam Fabry Perot Laser Interferometry. The 100 mm gun is used mainly for studies on initiation and detonation of high explosives [9,10] and the diagnostic most commonly used in these experiments incorporates manganin piezoresistive pressure gauges [11,12]. Rotating mirror, streaking, and moderate high-speed color and monochromatic digital cameras are also available. Performing experiments in the elevated temperature range (to 250°C) and cooled to liquid nitrogen temperature are also not uncommon.

Photographs of the new Dynamic Energetic Materials Impact and Ignition (DEMII) gun assembly can be seen in Fig. 1. The photographs show the gun set-up during fabrication at Physics Applications, Inc. before shipping, and all of the parts have been successfully pressure tested. As of this printing, some of the gun pieces have started to arrive at LLNL, with a few of the parts damaged in shipment and are being repaired before final installation. This paper will provide a general description of the new gun, describe the facility location and mounting details, point out the features of the gas pressure breech design, highlight the barrels and recoil system, provide an overview of the pressure system, and briefly touch on the future applications of the gun.

Fig.1. Photographs of the new Dynamic Energetic Materials Impact and Ignition (DEMII) gun system showing 3 different views of the portable gun system during fabrication at Physics Applications, Inc. before shipment to LLNL.

DETAILS DESCRIBING THE NEW DEMII GUN CAPABILITY

As with most facilities, the High Explosive Applications Facility has limited space and designed the new gun as a portable system that can be transported into the 100 mm gun explosive firing tank. This "dual use" allows the new gun to utilize the existing catcher system in place for the 100 mm gun. Figure 2 shows an artist rendering and photographs of the exterior of the 100 mm gun firing tank, and projectile stoppage plate system. Because the system is mobile, it is designed with a moveable gun on a test stand with a short barrel length of 1.8 meters (6 feet) with target assemblies placed on a stand that can support a multitude of experiments.

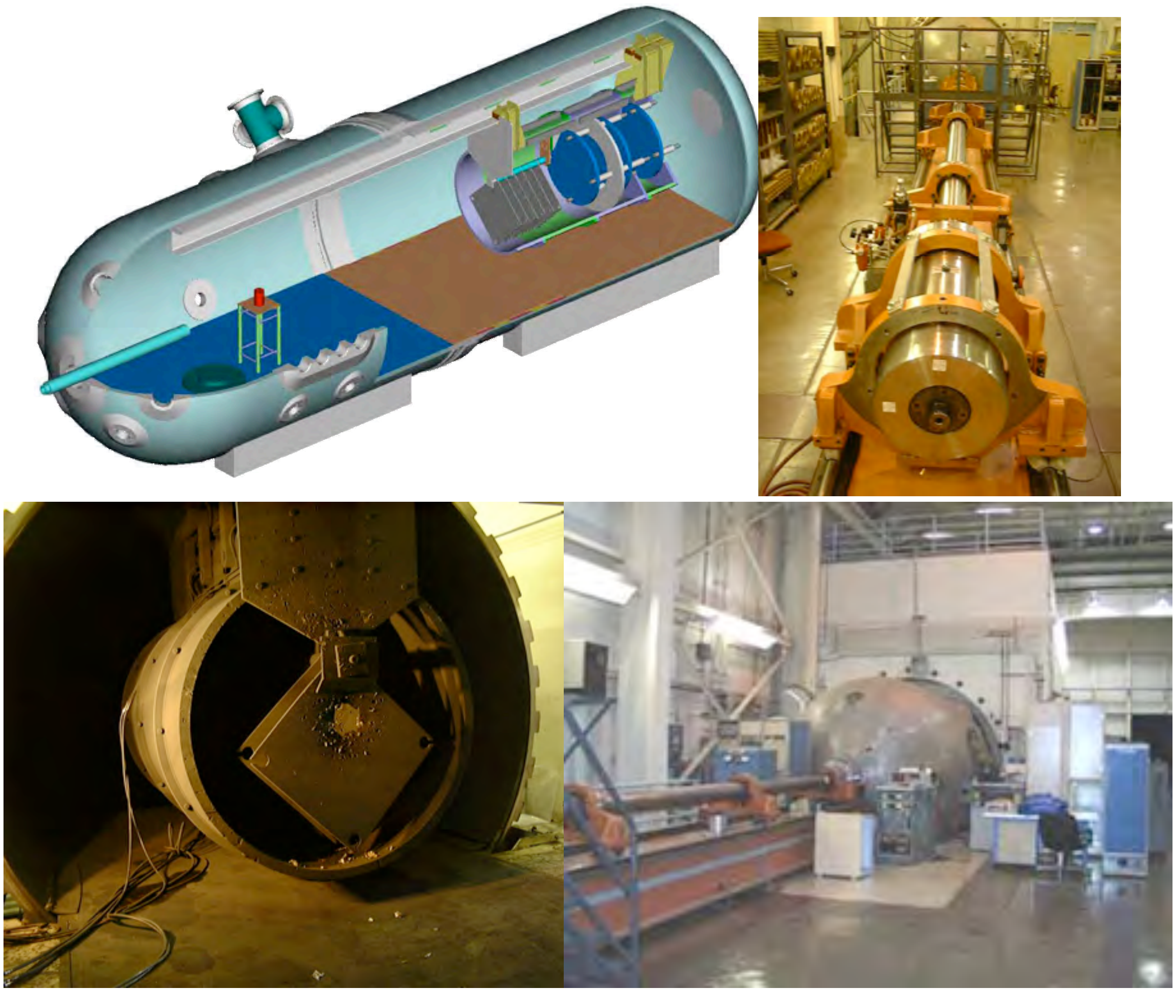

Fig. 2. An artist rendering (upper left) and photographs of the exterior of the 100 mm gun firing tank (upper and lower right), and jet stoppage system (below left).

Integrating the DEMII Gun and target stand into the HEAF gun tank is expected to be straightforward. A rendered drawing of the expected arrangement is shown in Figure 3 as well as the portable target stand to allow multiple experimental options. Naturally, the existing diagnostics in the tank can be utilized as previously mentioned.

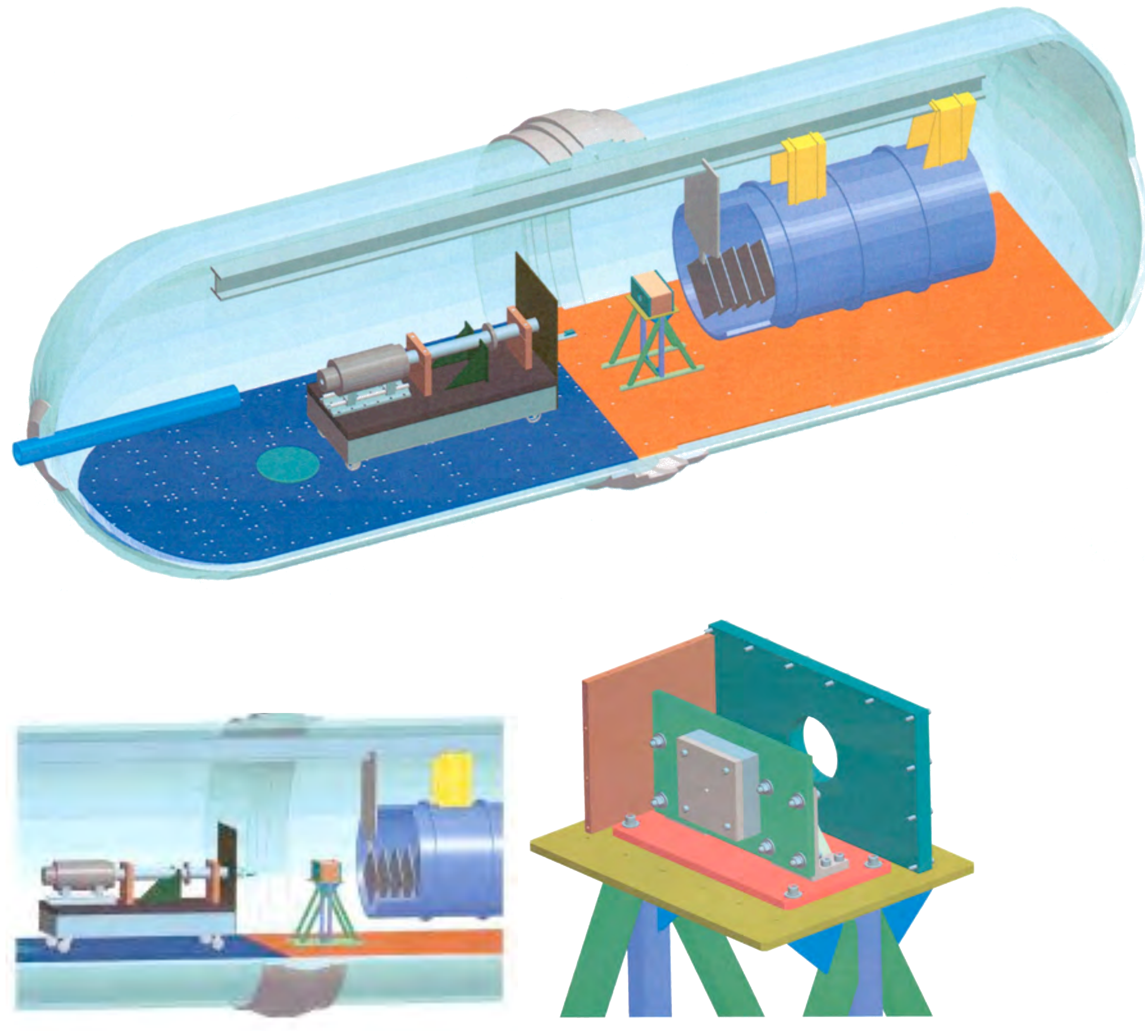

Fig.3. A rendering of the placement of the DEMII gun inside the HEAF gun firing tank using the existing projectile stoppage system (top) with a close-up side view shown (below left) and the target fixture/stand (below right).

The DEMII gun is mounted on a welded steel frame that is 2.2 m (90”) long x 1 m (40”) wide x 0.5 m (18)” high that provides the base for the mount assembly and supports the barrel. It moves on a set of four swivel casters and has threaded jack screws located near the four corners of the cart used to lift the cart off of its casters. These jack screws will be bolted to floor of the shot tank for rigid mounting as shown in Figure 4. The jack screws also provides 5 cm (2”) of vertical adjustment for leveling purposes with the breech and barrel mounted on a channel-shaped base plate that is supported on the top of the base cart with two pairs of tapered adjustment plates. An additional vertical adjustment of ±1.25 cm (1/2”) provides an angle movement to align barrel to the target. A Laser alignment system is also used to align the barrel to the target for aiming accuracy.

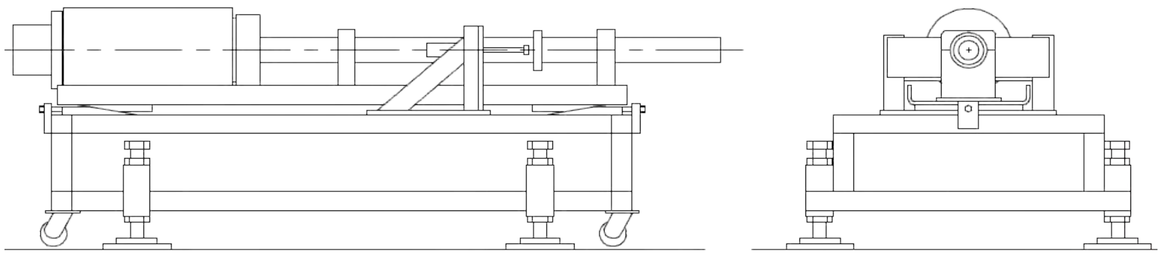

Fig.4. A computer rendering of the DEMII gun system highlighting the gun portability with wheels and mounting system with screw jacks to mount inside the 100 mm gun firing tank.

The new gas gun is equipped with two gas breech assemblies as a result of the significant difference in the pressure required to attain the desired high and low regimes of the velocity range. A Regenerative Valve Breech was chosen as the main operation that has no limit on projectile shape and uses no expendable parts. This "High-Performance Breech" has a 20 L volume with a 45 MPa (6,500 psi) Maximum Operating Pressure (MOP) with a nickel plating applied for corrosion resistance during storage. This "regenerative" valve design is shown in Figure 5 and works by first pressurizing the breech assembly and moving the valve assembly to allow the compressed gas to accelerate the projectile.

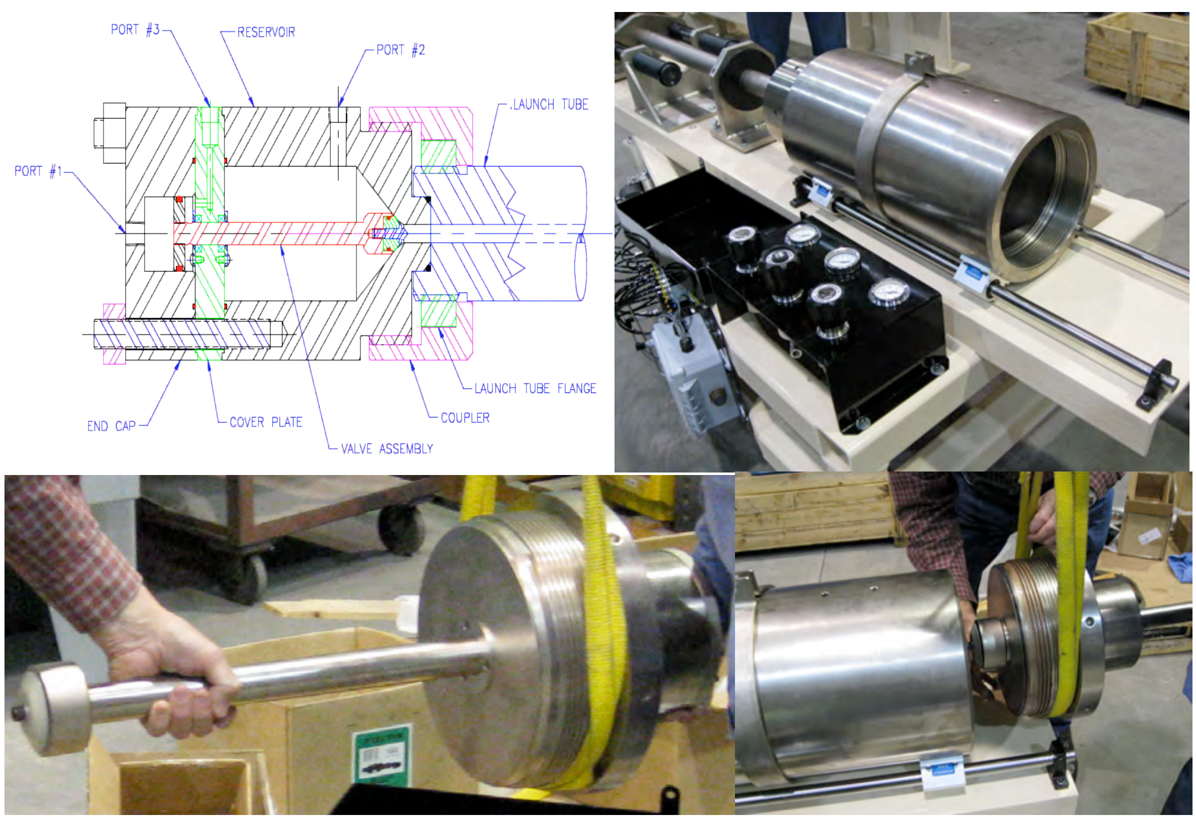

Fig.5. A schematic drawing (upper left) and photographs showing the breech assembly (upper right) and regenerative valve assembly (lower left) being inserted into the breech (lower right).

A Low Performance Breech is also included to be used at lower velocities (estimated at ~10-50 m/s range depending on the chosen projectile mass) and is shown in Figure 6. The Low-Performance Breech (2 L volume) uses a simple ball valve that incorporates an expendable plastic shear pin with a gas actuator. This comes with a 2 L accumulator volume and has a 2 MPa (300 psi) Maximum Operation Pressure (MOP).

Fig.6. A photograph showing the "low performance" breech consisting of a gas accumulator tank with an attached ball valve with screw threads to attach the unit to the breech assembly.

The DEMII gun also utilizes a simple recoil system consisting of 2 hydraulic shock absorbers that are mounted to base cart frame and engage a ring clamped to the barrel as shown in Figure 7. The frame that holds the shock absorbers is separated from the channel plate where gun components are mounted with an expected recoil travel of approximately 15 cm (6 inches). The system is capable of handling a maximum projectile momentum of 1,500 N-s (e.g. 6 kg at 250 m/s) while producing a maximum reaction force of approximately 22,000 N (5,000 lb).

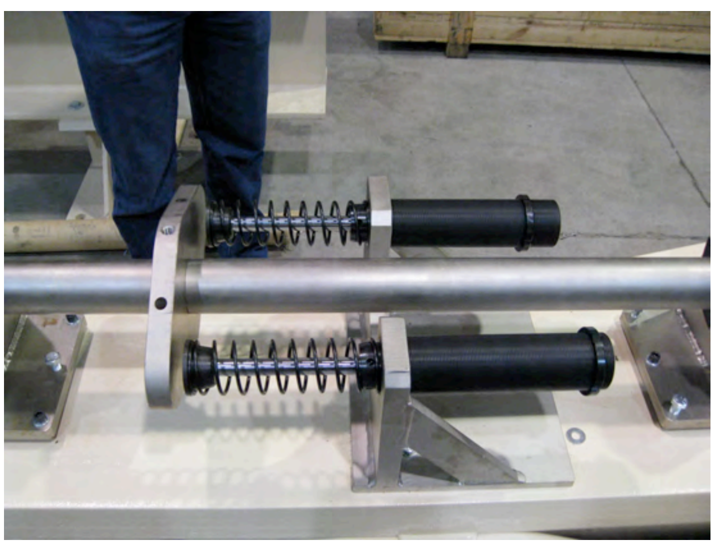

Fig.7. Photograph showing the simple recoil system used on the DEMII gun assembly.

The interchangeable barrels have inner diameters of 25.4 mm, 50.8 mm, and 76.2 mm (1, 2 and 3 inch) with a length of 1.8 m (6 ft). The different sizes allow it to be used for a variety of experiments to accommodate different sized projectiles. These barrels are made from seamless carbon steel tubing and have a threaded flange that engages a thread cut on the outside of the up-range tube end. A common coupling nut is then used to fasten the launch tube to the gas breech. The barrel to breech connection assembly and additional barrels not shown in the earlier photographs are shown in Figure 8. Because the gun is portable and will be stored for periods of time between use, a zinc coating was applied to the barrel and barrel plugs.

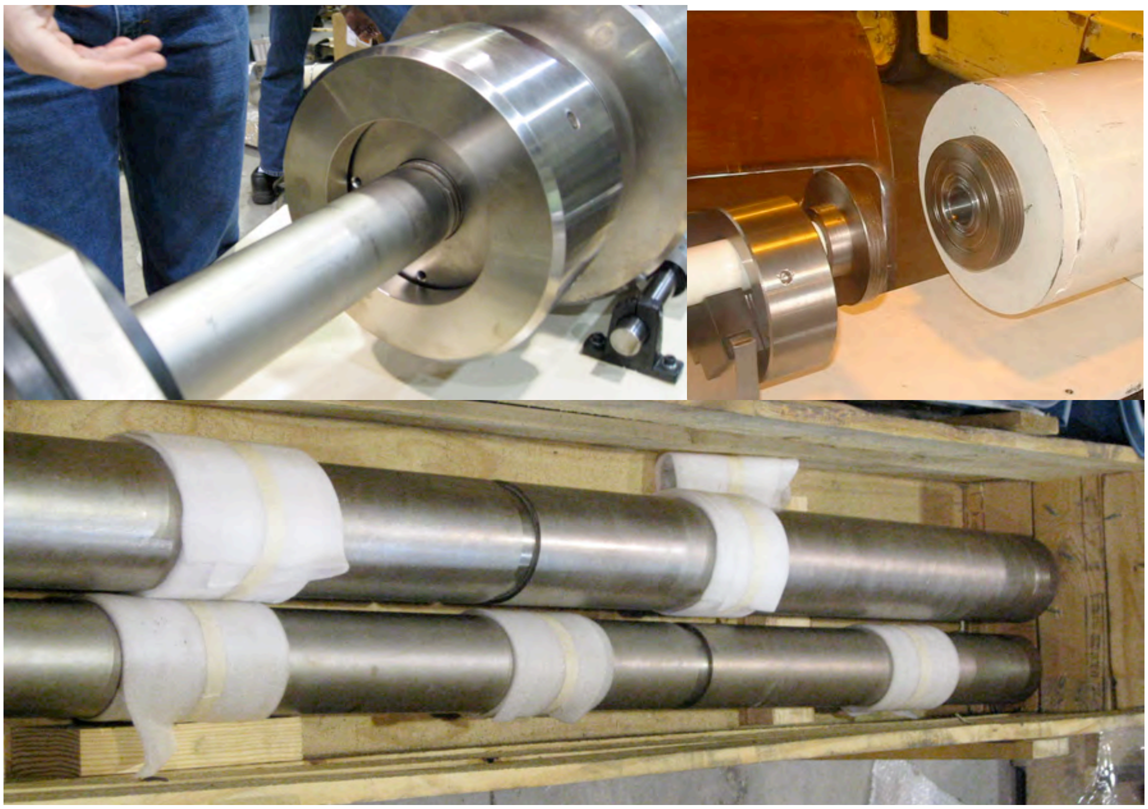

Fig.8. Photographs showing the barrel connection into the breech assembly (upper left), an example of the breech assembly disconnected from the barrel using a common coupling nut (upper right) and the additional barrels (bottom).

The projectile velocity measurement system will use a laser-interrupt detection design with two laser/detector stations. The system records the time interval between the two stations mounted to a frame on the downrange end of cart. Shielding from muzzle blast as well as debris from a target reaction is also planned to be incorporated into this design in the form of an aluminum or sheet metal plate and will be bolted on the wheeled cart of the gun base. A rendering of this concept is shown in Figure 9 and may change slightly as the new gun is brought on-line and tested.

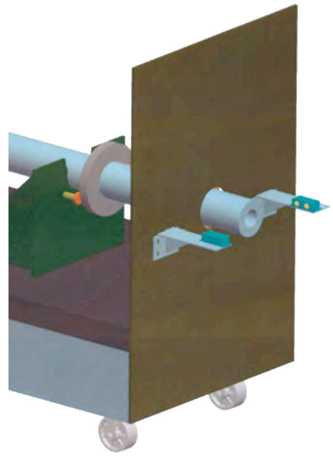

Fig.9. A computer rendering of an example blast shield with the laser velocity measurement blocks that will be utilized when performing experiments on the DEMII gun.

The DEMII gun uses a gas booster to pressurize the gas reservoir to levels up to 45 MPa (6,500 psi) for use with the regenerative valve breech with plans to use dry air or nitrogen with helium as a possibility if needed. The gas booster is supplied by standard gas bottles with a base pressure of 14 MPa (2,000 psi), and the system is capable of pressurizing the gas reservoir to its MOP of 45 MPa (6,500 psi) in approximately 10 minutes using this supply source. An air pressure switch and relief valve are incorporated in the system to limit the peak pressure produced by the booster and to bleed of the pressure if the it is decided to not fire after pressurization.

All of the regulators and valves that are used to operate the gun will be installed in an enclosed panel with a single dry air or nitrogen input from the gas booster and can be seen in Figure 10. For each shot, the regulators will be set to control the reservoir pressure, the pressure that "closes" the valve, and the "firing" pressure via a control panel. The pressures within the gas system will be monitored with pressure transducers during the pressurizing and filling operation. The system will be capable of venting the gas in the reservoir to obtain a lower shot pressure or to abort a shot as an added safety feature. The gas manifold system is attached to gun cart as described above with the gas bottles, booster system, and diagnostics located external to firing tank. The supply piping is designed to be simple and easy to implement with all fittings < 68 MPa (10,000 psi). A general schematic of the overall pressure system is shown in Figure 11.

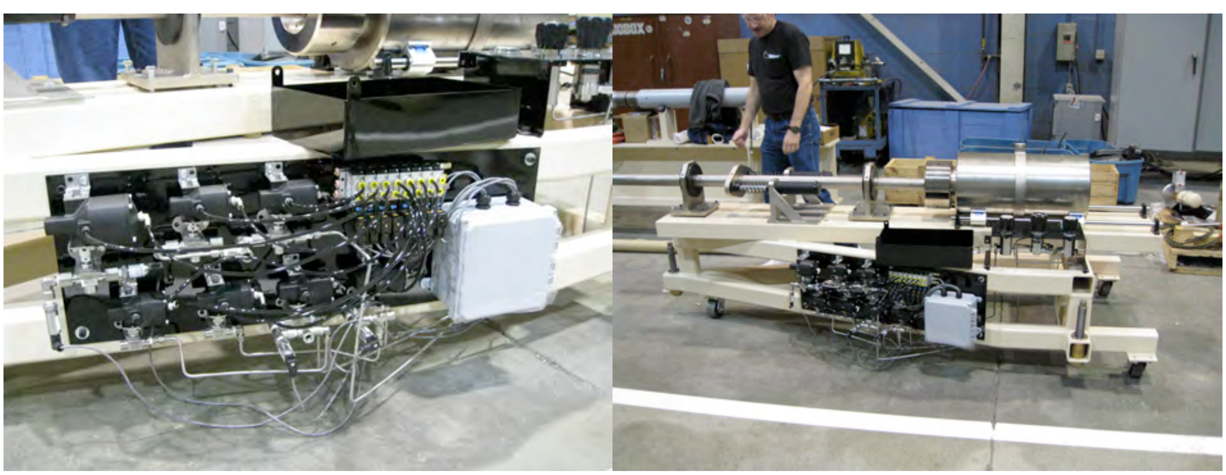

Fig.10. Photographs highlighting the gas actuating system assembled onto the portable gun cart.

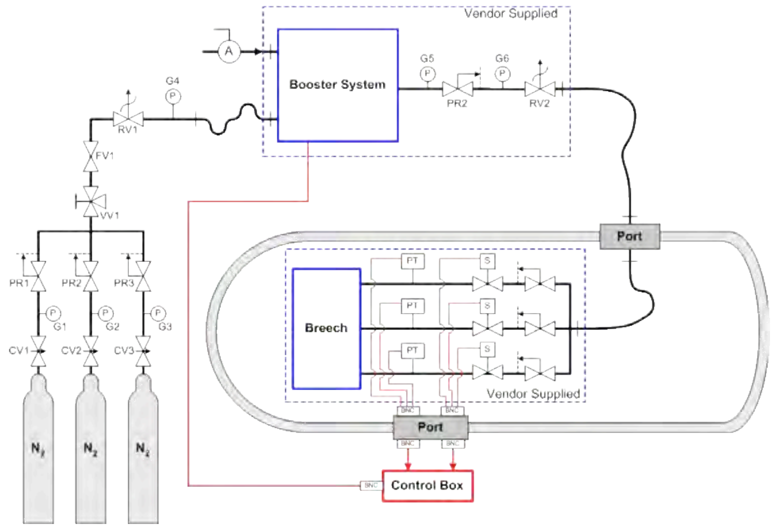

Fig.11. A schematic of the gas supply and pressure system for firing the DEMII gun.

The DEMII gun will be fired remotely from the gun tank control room, which is across the hall from the high-bay that encloses the firing tank. A schematic of the control system and general connections needed to operate the gun are shown in Figure 12 and is similar to what is commonly used in other facilities.

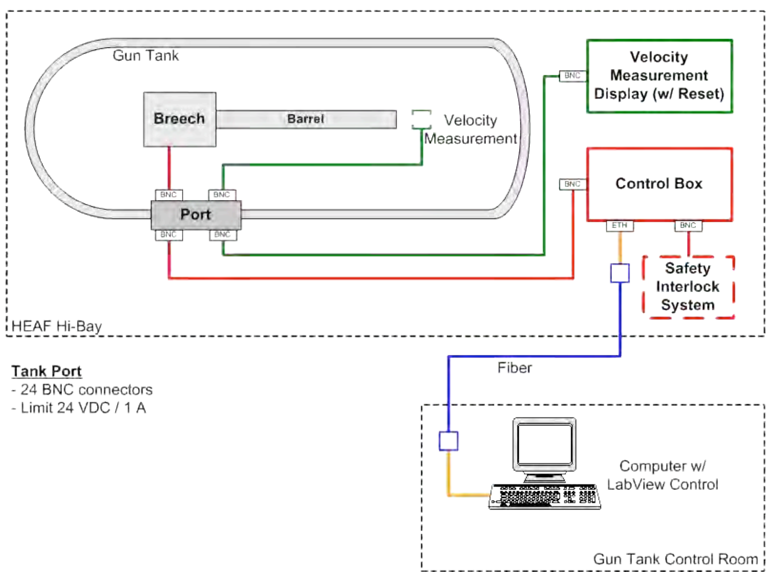

Fig.12. Overview schematic of the control system and connections needed to fire the DEMII gun remotely from the control room.

PLANNED RESEACH WITH NEW GUN CAPABILITY

We have established several research paths to take with the new Dynamic Energetic Material Impact and Ignition (DEMII) Gun capability. The main advantage is that it will bridge two of our current capabilities, the Low Speed Impact (LSI) impact table that is limited to about 6 m/s with a 4.1 kg mass and the 100 mm gun that fires from ~300 m/s to 2.5 km/s. The DEMII gun allows masses from 100 g to 4.1 kg and velocities from 10 m/s up to 300 m/s to be fired and fills this gap nicely. Therefore, it will be well suited to perform the impact tests of detonator assemblies and booster materials (extending the range of the Low Speed Impact (LSI) table), the Steven Impact Test (an explosive safety test), and materials science studies using the Taylor and Reverse Taylor test. Naturally, any other impact tests desired can also be performed using this capability.

The DEMII gun will expand on earlier research that used a Low Speed Impact (LSI) tester by extending the velocity range. This tester is mainly used to drive a "low-speed" insult into a detonator, booster, or detonator/booster assembly and mainly produces an ignition reaction or deflagration at a low velocity with no detonations observed. These experiments simulate accident environments seen during the assembly process and in the field with impact of bolts, screwdrivers, and other tools. The goal is to determine the insult threshold to detonator and booster materials under "Friction" and/or "pinch" initiation and calculate initiation probabilities. A rendition of the Low Speed Impact (LSI) test table used for impacts into booster materials and detonator assemblies is shown in Figure 13. Also shown in the Figure are photographs of a flathead screwdriver impact into a booster material and a hardened pin impacted into a detonator can assembly.

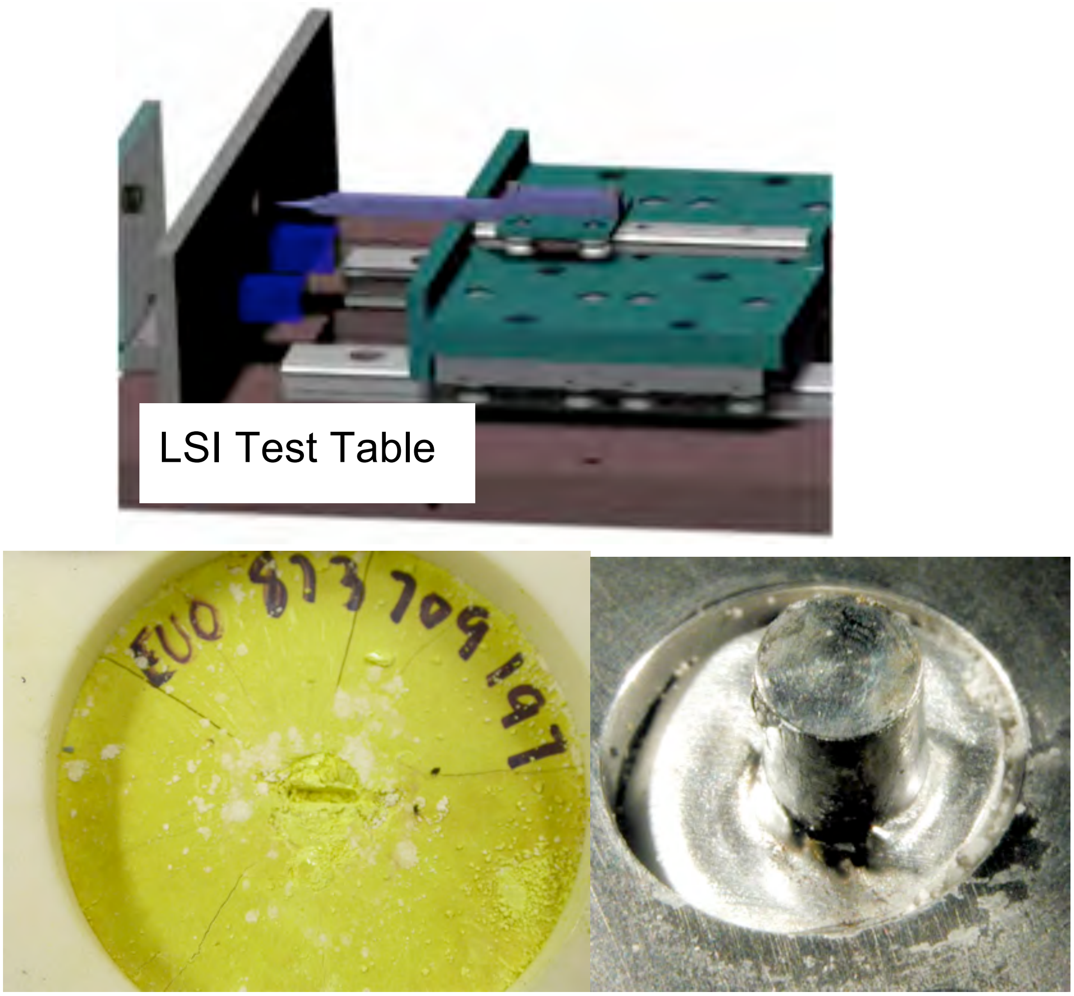

Fig. 13 A rendition of the Low Speed Impact (LSI) test table (above) used for impacts into booster materials and detonator assemblies. Also shown are photographs of a flathead screwdriver impact into a booster material (lower left) and a hardened pin impacted into a detonator can assembly (lower right).

The Steven Impact Test [6, 15, 16] involves impacting a target with High Explosives (HE) at increasingly higher velocities with a projectile until you get a "GO" (reaction). A burning or deflagration process is generally observed in lieu of a full-scale detonation. The lowest velocity where you get a "GO" is considered the "reaction threshold" and typically involves several experiments to determine. Violence level data can be obtained from blast overpressure gauges and acoustic microphones placed near the experiment. Both the "reaction threshold" and violence level data can be utilized in various hydrodynamic reactive flow models to generate safety predictions for a variety of scenarios.

The experimental geometry of the Steven Impact Test target with projectile head is shown in Figure 14. The projectile head consists of a steel cylinder with a 30.05 mm radius hemispherical impact surface and mass of 1.2 kg. A gas gun accelerates the steel projectile head attached to an aluminum sabot into a 110 mm diameter by 12.85 mm thick explosive charge confined by a 3.18 mm thick steel plate on the impact face, a 19.05 mm thick steel plate on the rear surface, and 26.7 mm thick steel side confinement. A Teflon ring around the explosive provides radial confinement.

Normally for these experiments, a 76 mm diameter smooth bore gas gun located at LLNL Site 300, bunker 850 would be utilized that fires onto an outdoor firing table. However, this bunker has since been closed down and the DEMII gun will replace this gun capability to perform theses experiments.

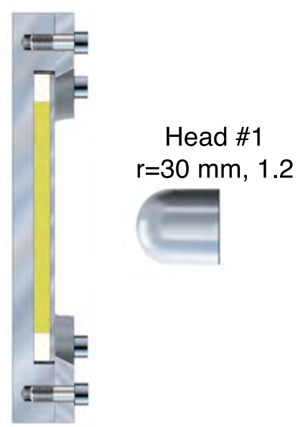

Fig. 14. Schematic diagram of the Steven Impact Test arrangement with the most common projectile head.

The Taylor test can be used for high strain rate material studies and an instrumented reverse Taylor test [17,18] can be seen in Figure 15. This test is used to characterize dynamic deformation behavior during high-strain rate loading as well as validate computational models. These experiments help identify minimum impact velocity necessary to induce plastic deformation (relative strength measure). The high-speed photography diagnostic can be used to capture incremental transient deformation (strain measure) and velocity interferometry for characterizing elastic/plastic wave interactions and identify material fracture or failure. While the material shown is an Al + Fe_2O_3 powder in an epoxy matrix, experiments on plastic bonded explosive (PBX) material to understand the dynamic fracture behavior are planned.

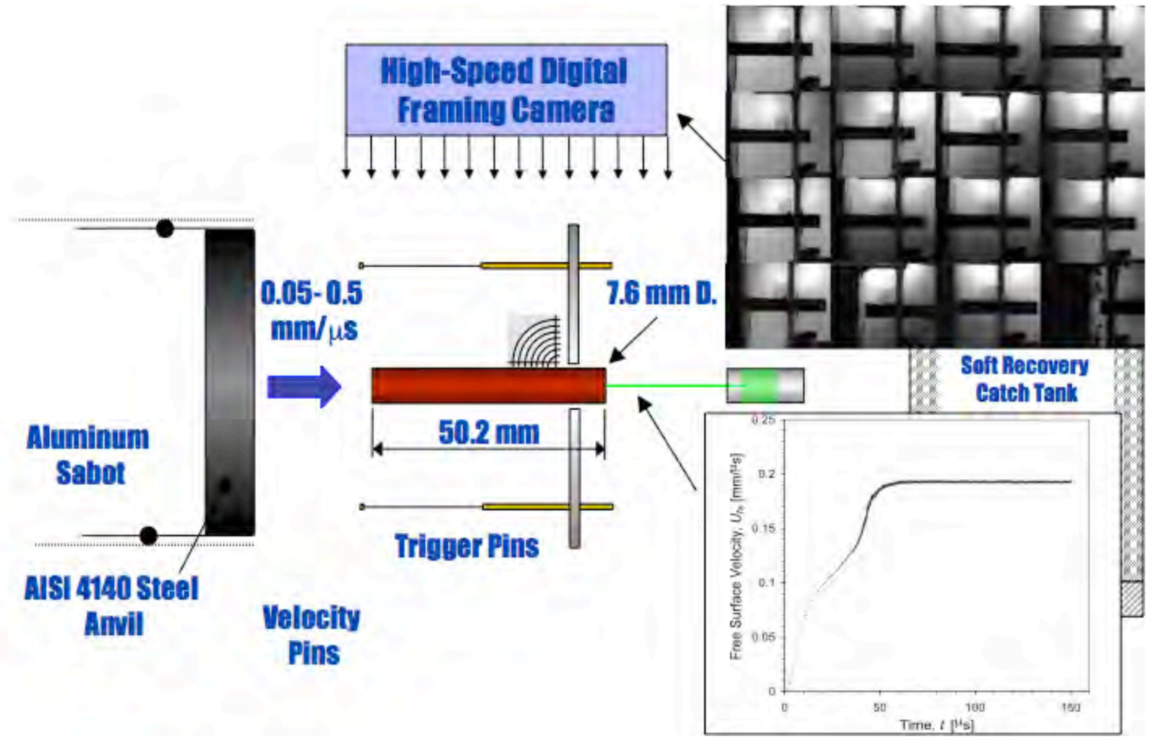

Fig.15. A schematic showing an experiment and results from a Reverse Taylor Impact test on an energetic structural material [17, 18].

SUMMARY

The Dynamic Energetic Materials Impact and Ignition (DEMII) Gas Gun will be a versatile experimental tool that is currently being implemented at the Lawrence Livermore National Laboratory (LLNL) High Explosives Applications Facility (HEAF). The new gun meets our project requirements by bridging other capabilities within the facility, ability to be used inside a firing tank without any new facility space needed, allowing up to a 4.1 projectile kg mass accelerated in range of ~10-300 m/s velocity, incorporates interchangeable 25.4, 50.8, and 76.2 mm barrels, utilizes straightforward "regenerative valve" and "ball-valve" breech designs, has the capabilities to be used with multiple experiments, and being portable and easy to use. This gun system has just been shipped for use and parts are being received after being designed and fabricated by Physics Applications, Inc in Dayton, Ohio.

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REFERENCES

1. D.L. Banner and C.A. Honodel, "Gun Facilities for One-dimentional Shock Wave Research at the Lawrence Livermore Laboratory," Proceedings of the 25th Aeroballistic Range Association, USN/NOL, October 1, 1974.

2. Leroy M. Erickson, “The 4 inch Light Gas Gun at LLL and it’s Use for Detonation Physics Experiments,” Proceedings of the 30th Aeroballistic Range Association, October 1979.
3. C. Honodel, “Lawrence Livermore National Laboratory’s High-Explosives Application Facility—Nearing Completion,” Proceedings of the 39th Meeting of the Aeroballistic Range Association, Albuquerque, NM, October 10-13, 1988.
4. F. Rienecker, C. Honodel, R. Waldron, E. Moor, S. Perfect, and R. Bast, “The LLNL 150-mm Equation-of-State Gun System,” Proceedings of the 38th Meeting of the Aeroballistic Range Association, Tokyo, Japan, October 6-9, 1987.
5. Kevin S. Vandersall, Roanne A. Lee, Paul I Chiao, Frank Garcia, James O. Travis, and Jerry W. Forbes, “New 100 mm Gun Assembly Installation at Lawrence Livermore National Laboratory High Explosives Applications Facility,” Proceedings of the 54th meeting of the Aeroballistic Range Association, Albuquerque/Santa Fe, NM, October 19-24, 2003.
6. Kevin S. Vandersall, Lori L. Switzer, and Frank Garcia, “Threshold Studies on TNT, Composition B, and C-4 Explosives using the Steven Impact Test,” Presented at the 56th annual Aeroballistic Range Association meeting, October 2-7, 2005, Houston, TX.
7. Kevin S. Vandersall, Lori L. Switzer, Steven K. Chidester, and Frank Garcia, 155 mm Gun Capabilities at Lawrence Livermore National Laboratory, 57th meeting of the Aeroballistic Range Association, Palazzo Franchetti, Venice, Italy September 18-22, 2006.
8. Information on the High Explosives Applications Facility at Lawrence Livermore National Laboratory can be obtained on the internet at the following address: https://wci.llnl.gov/fac/heaf/index.html
9. Paul A. Urtiew, Jerry W. Forbes, Craig M. Tarver, Kevin S. Vandersall, Frank Garcia, Daniel W. Greenwood, Peter C. Hsu, Jon L. Maienschein, “Shock Sensitivity of LX-04 with Delta Phase HMX at Elevated Temperatures,” 13th APS Topical Conference on Shock Compression of Condensed Matter, July 20-25, 2003, Portland, Oregon.
10. Kevin S. Vandersall, Jerry W. Forbes, Craig M. Tarver, Paul A. Urtiew, and Frank Garcia, “Re-Shock Experiments in LX-17 to Investigate Reacted Equation of State” Shock Compression of Condensed Matter-2001, Furnish, M. D., Thadhani, N. N., and Horie, Y, eds. CP-620, AIP Press, New York, (2002) 153-156.
11. Vantine, H. C., Erickson, L.M., and Janzen, J., “ Hysteresis-Corrected Calibration of Manganin under Shock Loading,” J. Appl. Phys., 51(4), pp. 1957-1962. (1980).
12. Vantine H., Chan J., Erickson L. M., Janzen J., Lee R. and Weingart R. C., "Precision Stress Measurements in Severe Shock-Wave Environments with Low Impedance Manganin Gauges," Rev. Sci. Instr., 51: 116-122, (1980).
13. Chiao, Paul, “Low Speed Impact Tests,” Internal LLNL presentation CODTU-2008-1697, Sept. 18, 2007.
14. Hrousis, Constantine, "Mini-Review of MSAD Low Speed Impact Tests," Internal LLNL presentation CODTU-2006-1018, August 18, 2006.
15. Steven K. Chidester, Kevin S. Vandersall, Lori L. Switzer, Daniel W. Greenwood, and Craig M. Tarver, “LX-04 Violence Measurements: Steven Tests Impacted by Projectiles Shot from a Howitzer Gun,” presented at the 14th APS Topical Conference on Shock Compression of Condensed Matter, July 31 – August 5, 2005, Baltimore, Maryland.
16. Lori L. Switzer, Kevin S. Vandersall, Steven K. Chidester, Daniel W. Greenwood, and Craig M. Tarver, “Threshold Studies of Heated HMX-Based Energetic Material Targets Using the Steven Impact Test,” Shock Compression of Condensed Matter-2003, edited by M.D. Furnish, Y.M. Gupta, and J.W. Forbes, pp. 1045-1048, 2004.
17. L. Ferranti, Jr., "Mechanical Reactions and Strengthening in Epoxy-Cast Aluminum Iron-Oxide Mixtures," Doctoral Thesis, Georgia Institute of Technology, 2007.
18. L. Ferranti, Jr. and N. N. Thadhani, "Dynamic Mechanical Behavior Characterization of Epoxy-Cast Al+Fe2O3 Thermite Mixtures," Met. Trans. A. 38A 2697-2715 (2007).